ABSTRACT AND REFERENCES

APPLIED MECHANICS

DEVELOPMENT OF THE STRAIN–RATE AND TEMPERATURE SENSITIVE THEORY OF MICROSTRAIN (p. 4–9)

Inna Onyshchenko, Iurii Cherniakov, Volodymyr Shneider

Plastic flow, caused by the dislocation glide is closely related to the thermal activation mechanism in a wide range of strain rates. On the other hand, the high-rate plastic strain may lead to an apparent increase in temperature. Therefore, the influence of strain rate and temperature are usually related and should be considered both in the study of the materials behavior, depending on the strain rate.

Over the past three decades, this approach has been implemented in a number of the continuum and physical theories of thermo-viscoelasticity that lead to rather complicated constitutive relations and their use is restricted mainly by simple loading processes.

A generalized version of the theory of microstrain, which is sufficiently simple and suitable to describe the finite visco-plastic strain in a wide range of strain rates and temperatures was proposed. Constitutive relations of the theory that are applicable not only under simple, but also complex loading were built. The algorithm for their numerical implementation, which allows to take into account not only the plurality of active microplastic strains but also possibility to set an arbitrary loading trajectory was proposed. A comparison of the charts of uniaxial tension at various strain rates obtained using the theory of microstrain with the known experimental data was performed. It is shown that the proposed option allows to achieve a satisfactory description of experiments with a small number of material constants, which simplifies the calibration of the theory.

The results significantly extend the capabilities of the theory of microstrain and open up prospects for its use to describe the visco-plastic flow and solve applied tasks under complex loading.

Keywords: theory of microstrain, finite strain, viscoplasticity, strain rate, temperature.

References

1. Taylor, G. I. (1938). Plastic strain in metals. J. Inst. Metals, 62, 307–325.
2. Zener, C., Hollomon, J. H. (1944). Effect of strain rate upon plastic flow of steel. J. Appl. Phys., 15, 22–32.
3. Follansbee, P. S., Kocks, U. F. (1988). A constitutive description of the deformation of copper based on the use of the mechanical threshold stress as an internal state variable. Acta Metallurgica, 36 (1), 81–93. doi: 10.1016/0001-6160(88)90030-2
4. Zerilli, F. J., Armstrong, R. W. (1992). The effect of dislocation drag on the stress-strain behavior of F.C.C. metals. Acta Metallurgica et Materialia, 40 (8), 1803–1808. doi: 10.1016/0956-7151(92)90166-c
5. Miller, A. K., Krauss, A. S., Krauss, K. (1996). Improvements in the MATMOD equations for modeling solute effects and yield–surface distorsion. Unified Constitutive Laws of Plastic Deformation. Academic Press Inc., 153–227.
6. Nemat-Nasser, S., Li, Y. (1998). Flow stress of f.c.c. polycrystals with application to OFHC Cu. Acta Materialia, 46 (2), 565–577. doi: 10.1016/s1359-6454(97)00230-9
7. Khan, A. S., Liang, R. (2000). Behaviors of three BCC metals during non-proportional multi-axial loadings: experiments and modeling. International Journal of Plasticity, 16 (12), 1443–1458. doi: 10.1016/s0749-6419(00)00016-4
8. Kocks, U. F., Mecking, H. (2003). Physics and phenomenology of strain hardening: the FCC case. Progress in Materials Science, 48 (3), 171–273. doi: 10.1016/s0079-6425(02)00003-8
9. Beyerlein, I. J., Tomé, C. N. (2008). A dislocation-based constitutive law for pure Zr including temperature effects. International Journal of Plasticity, 24 (5), 867–895. doi: 10.1016/j.ijplas.2007.07.017
10. Chaboche, J. L. (2008). A review of some plasticity and viscoplasticity constitutive theories. International Journal of Plasticity, 24 (10), 1642–1693. doi: 10.1016/j.ijplas.2008.03.009
11. Rusinek, A., Rodríguez-Martínez, J. A., Klepaczko, J. R., Pęcherski, R. B. (2009). Analysis of thermo-visco-plastic behaviour of six high strength steels. Materials & Design, 30 (5), 1748–1761. doi: 10.1016/j.matdes.2008.07.034
12. Cai, M.-C., Niu, L.-S., Ma, X.-F., Shi, H.-J. (2010). A constitutive description of the strain rate and temperature effects on the mechanical behavior of materials. Mechanics of Materials, 42 (8), 774–781. doi: 10.1016/j.mechmat.2010.06.006
13. Grèze, R., Manach, P. Y., Laurent, H., Thuillier, S., Menezes, L. F. (2010). Influence of the temperature on residual stresses and springback effect in an aluminium alloy. International Journal of Mechanical Sciences, 52 (9), 1094–1100. doi: 10.1016/j.ijmecsci.2010.04.008
14. Gao, C. Y., Zhang, L. C. (2012). Constitutive modelling of plasticity of fcc metals under extremely high strain rates. International Journal of Plasticity, 32-33, 121–133. doi: 10.1016/j.ijplas.2011.12.001
15. Knezevic, M., McCabe, R. J., Tomé, C. N., Lebensohn, R. A., Chen, S. R., Cady, C. M., Gray III, G. T., Mihaila, B. (2013). Modeling mechanical response and texture evolution of α-uranium as a function of strain rate and temperature using polycrystal plasticity. International Journal of Plasticity, 43, 70–84. doi: 10.1016/j.ijplas.2012.10.011
16. Hor, A., Morel, F., Lebrun, J.-L., Germain, G. (2013). An experimental investigation of the behaviour of steels over large temperature and strain rate ranges. International Journal of Mechanical Sciences, 67, 108–122. doi: 10.1016/j.ijmecsci.2013.01.003
17. Novogilov, V. V., Kadashevich, Yu. I., Chernyakov Yu. A. (1985). Teoriia plastichnosti, uchity`vaiushchaia mikrodeformatcii. Journal of Engineering Materials and Technology, 284, 821–823.
18. Kadashevich, Yu. I., Chernyakov, Yu. A. (1992). Theory of plasticity, taking into account microstresses. Advances in mechanics, 15 (3–4), 3–39.
19. Chernyakov, Y. A., Polishchuk, A. S., Shneider, V. P. (2011). On extension of the phenomenological approach in the theory of plasticity. Journal of Engineering Mathematics, 78 (1), 55–66. doi: 10.1007/s10665-011-9470-8
20. Onischenko, I. S., Chernykov, Yu. A., Shneider, V. P. (2014). Numerical integration of the equations of the theory of creep, which taken into account the microstrains. Problems of Computational Mechanics and strength of structures, technologies, 22, 281–290.
21. Dafalias, Y. F. (1990). The plastic spin in viscoplasticity. International Journal of Solids and Structures, 26 (2), 149–163. doi: 10.1016/0020-7683(90)90048-z
22. Lee, E. H. (1969). Elastic-Plastic Deformation at Finite Strains. Journal of Applied Mechanics, 36 (1), 1–6. doi:10.1115/1.3564580

METHOD OF EXCITATION OF DUAL FREQUENCY VIBRATIONS BY PASSIVE AUTOBALANCERS (p. 9–14)

Gennadiy Filimonikhin, Volodymyr Yatsun

Using ball, roller and pendulum autobalancers as dual-frequency vibration exciters was proposed, corresponding designs were developed.

Kinematic diagrams of machines with different platform movements (plane or rectilinear translational, vibrational-rotational, plane-parallel, etc.), on which dual-frequency vibration exciters can be installed were proposed.

One of the technical solutions was tested by 3D modeling in SolidWorks CAD system using the CosmosMotion module.

Considered dual-frequency vibration exciters have complex structures, it is difficult to tune the resonance vibration frequency of the platform, etc. Therefore, a new method of excitation of dual-frequency vibrations in the resonance vibromachines, eliminating these disadvantages was developed in the paper.

For excitation of dual-frequency vibrations, using a special movement regime of the rotor with AB – quasiperiodic was proposed. In it, the rotor rotates at the resonance speed, and CW in AB can not catch up with the rotor since they are stuck at one of its resonance rotation frequencies.

One of the proposed technical solutions was tested in Solidworks CAD system using the Motion module. A 3D model of the vibration machine with vibroexciter in the form of ball autobalancer

was developed and simulation has shown the following: the possibility of using autobalancer for the two-frequency vibration excitation in the resonance vibration machines was confirmed; features of dual-frequency vibrations can be varied within wide limits by changing the mass of corrector weights, unbalance mass in the auto-balancer housing, rotor speed.

Application of new vibroexciters will allow to create new vibromacnines with the dual-frequency vibration of the platform. The energy efficiency of these machines will be provided by the fact that the lower vibration frequency of the platform will coincide with its resonance frequency, which will provide intense vibrations of the platform necessary to perform the basic technological operation. Further intensification of technological processes will be ensured by self-cleaning of the screen and changes in the mechanical properties of the material processed by fast vibrations.

Keywords: vibroexciter, dual-frequency vibration, unbalance, resonance vibromacine, autobalancer, corrector weight, screen.

References

1. Azbel, G. G., Blekhman, I. I., Bykhovsky, I. I. et al.; In: Lavendel, E. E. (1981). Vibration technique. Vol. 4. Vibrating processes and machines. Moscow: Mashinostroenie, 509.
2. Humphrey, C. T. (USA). (13.11.1984). Dual frequency vibratory screen for classifying granular material. Patent US 4482455 USA. Appl. № US 06/367,122. Filed 09.04.1982.
3. Hurskyi, V. M., Kuzo, I. V., Lanets, O. V. (2010). Providing dual-frequency resonant modes of vibration table compaction concrete mixes. Proceedings of the National University "Lviv Polytechnic". Serie "Dynamics, durability and design of machines and devices", 678, 44–51.
4. Kartavy, A. N. (2009). Resource-Saving Principles of Technological Vibration Machines Construction. Mining machinery and electrical engineering, 3, 28–37.
5. Lanets, O. S. (2008). Highly resonant vibration machine with electromagnetic actuator (Theoretical bases and practice of creation). Lviv: Publishing Nat. Univ "Lviv Polytechnic", 324.
6. Koshelev, A. V. (2014). Investigation of the efficiency of parametric resonance drive to improve vibrating mills. Nizhnii Novgorod, 125.
7. Bukin, S. L., Maslov, S. G., Ljutyj, A. P., Reznichenko, G. L. (2009). Intensification of technological processes through the implementation of vibrators biharmonic modes. Enrichment of minerals: Scientific and technical journal, 36–37 (77–78), 81–89.
8. Exciter. Available at: https://ru.wikipedia.org/wiki/Вибровозбудитель
9. Zongzhan Liu (CN), Fuhua Jia (CN); assignee: Chaoyang vibration machinery. (1992). Electromagnetic vibrator with V-shaped working face of air gap. Patent CN 2098971. Appl. № CN2098971 U. Filed 18.12.1990.
10. RHEWUM GmbH. RHEWUM DF The screening machine type DF is a high performance-screening machine for medium and coarse separation range. Available at: http://www.rhewum.com/ru/produkty/dvukhchastotnye-proseivajushchie-mashiny/rhewum-df.html
11. Dudkin, M. V., Sakimov, M. A., Kuznetsov, P. S. (2005). General classification structures of asymmetric planetary exciters road machines. Journal of VKGTU D. Serikbaeva, 1, 37–44.
12. Gerasimov, M. D., Gerasimov, D. M., Isaev, I. K., Sharapov, R. R. (2014). Single-shaft planetary vibrator directed vibrations. Patent 2515336 Russian Federation, B06B1/00. Filed 01.08.2012. Bul. № 1.
13. Nadutyi, V. P., Perehrest, V. I., Yagniukova, I. V. (2014). The geometry and kinematics of the interaction in the system "roller – roller shaft" with the impactors. Vibration in engineering and technology, 2 (74), 29–33.
14. Krash I., Obodan Ju. (2006). Vibtek Endzhiniering Ltd. Multi vibration separator, vibrating separator and method of vibration separation. Patent of Ukraine 74544, B07B 1/42. Filed 28.03.2000. Bul. № 1, 27.
15. Nadutyi, V. P., Lapshin, E. S., Shevchenko, A. I., Burov, A. V. (2011). Increase of the moisture removal efficiency during mountain mass fines screening by means of sampling action. Scientific Bulletin of NGU, 2, 95–99.
16. Lapshin, E. S., Shevchenko, A. I., Burov, A. V. (2013). Ways of improvement of vibrational segregation and dehydration of mineral raw materials. Scientific Bulletin of NGU, 3, 45–51.
17. Filimonikhin, G. B., Yatsun, V. V. (2014). The use of passive autobalancer as dual-frequency circularly vibration exciter. Patent of Ukraine 92337, G01M 1/32, F04D 29/66. Filed 18.03.2014. Bul. № 15, 4.
18. Blehman, I. I. (1971). Synchronization of dynamical systems. Moscow: Nauka, 896.
19. Filimonikhin, G. B. (2004). Balancing and vibration protection of rotors by autobalancers with solid corrective weights. Kirovograd: KNTU, 352.
20. Filimonikhin, G. B., Yatsun, V. V. (2014). 3D modeling of the excitation autobalancer two-frequency oscillations platform screen by using Solidworks and Cosmos motion. Mathematical and simulation modeling systems, 218–221.
21. Filimonikhin, G., Goncharov, V. (2014). Parameters optimization of centrifugal juicer with auto-balancer by minimization of time of autobalancing occurred. Eastern-European Journal of Enterprise Technologies, 2/7 (68), 28–32. doi: 10.15587/1729-4061.2014.23317

CONSTRUCTIVE-TECHNOLOGICAL MODELING OF COMPOSITE CONSTRUCTIONS USING THE SYSTEM ANALYSIS (p. 15–20)

Vitaliy Pasichnyk, Oleksiy Khmurenko

Along with effective system analysis methods, the problem of the detailed description of objects and relations between them in systems is still topical in modeling composite constructions and technologies for their preparation. The problem is complicated by specific requirements for composite materials in the construction. Building and analysis of the composite construction model for classical assembly devices (with rigid basic elements) point out the unreasonableness of use, and as a result – of the assembly technology in general.

The proposed combined formalized model of the construction made of composite materials in the modular assembly allows to describe the above technology in detail and analyze the construction in all necessary areas and assembly parts without destroying the overall structure of the model. Concurrent deployment of components made of composite materials in the appropriate modular devices and their fixation by specialized tools allows to reduce the overall assembly cycle excluding labor-intensive fitting and refinement operations. The implementation algorithm of such technology with the possibility of inter-operation data control and correction using automated assembly equipment and systems was considered.

Keywords: constructive-technological model, composite constuction, modular assembly devices, systems analysis.

References

1. Pasichnyk, V. A., Khmurenko, O. O. (2015). Metodyka formuvannia spetsyfichnykh vymoh pry modeliuvanni kesonnykh konstruktsii iz polimernykh kompozytsiinykh materialiv. Visnyk NTUU «KPI». Seriia «Mashynobuduvannia», 74, 64–66.
2. Masiagin, V. B. (2013). Rasshirenie oblastei teoreticheskogo i prakticheskogo primeneniia razmernogo analiza v mashinostroenii. Mat. konf. SWorld. Perspective innovations in science, education, production and transport '2013. Tehnicheskie nauki – Mashinovedenie i mashinostroenie. Available at: http://www.sworld.com.ua/index.php/ru/technical-sciences-413/machines-and-mechanical-engineering-413/20796-413-0636
3. Masiagin, V. B., Martynov, V. G. (2012). Primenenie setei Petri pri modelirovanii shemy sborki. Materialy VII Mezhdunarodnoi nauchno-tehnicheskoi konferentsii. Sektsiia № 5. Tehnologii mehanicheskoi i fiziko-tehnicheskoi obrabotki, 323–327.
4. Primak, D. D., Volkov, I. A. (2014). Metodika postroeniia razmernyh tsepei s pomoshch'iu grafa modulei poverhnostei. Nauchnyi zhurnal «Vestnik magistratury, I (6(33)), 81–83.
5. Vysloukh, S. P., Filippova, M. V. (2006). Metodyka avtomatyzovanoho proektuvannia tekhnolohii skladannia vyrobiv pryladobuduvannia. Visnyk NTUU «KPI». Seriia «Mashynobuduvannia», 32, 111–117.
6. Korenkov, V. M., Subin, A. A. (2008). Metod strukturnoho syntezu ta otsinky alternatyv pry avtomatyzovanomu syntezi tekhnolohichnykh protsesiv skladannia vyrobiv. Visnyk ZhDTU. Seriia «Tekhnichni nauky», 4 (47), 155–160.
7. Korenkov, V. M. (2003). Model avtomatyzovanoho syntezu marshrutnoho tekhnolohichnoho protsesu skladannia vyrobiv. Visnyk tekhnolohichnoho universytetu Podillia, № 4, Part 2, 228–235.
8. Solomentsev, Yu. M., Chekmenev, S. E., Frolov, E. B., Kriukov, V. V. (2010). O problemah avtomatizatsii etapov zhiznennogo tsikla izdeliia. Vestnik MGTU "Stankin", 4 (12), 122–125.

9. Bozhko, A. N. (2011). Modelirovanie mehanicheskih sviazei izdeliia. Elektronnoe nauchno-tehnicheskoe izdanie «Nauka i obrazovanie». Available at: http://technomag.bmstu.ru/doc/182518.html
10. Pasichnyk, V. A. (2014). Binarni vidnoshennia obmezhen rukhlyvosti – osnova matematychnoho opysu skladalnykh vyrobiv. Suchasni tekhnolohii mekhano-skladalnoho vyrobnytstva, 1, 57–61.
11. Gonsales-Sabater, A. (1999). Sistema avtomatizirovannogo proektirovaniia tehnologii instrumental'nogo proizvodstva. Mashinostroitel', 4, 54–59.
12. Masiagin, V. B., Volgina, N. V. (2011). Semanticheskii podhod k avtomatizatsii kodirovaniia konstruktorsko-tehnologicheskoi informatsii. Mater. nauch.-tehn. konf. "Omskii region – mestorozhdenie vozmozhnostei". Omsk: OmGTU, 63–65.

SYNTHESIS OF ACTIVE COMPENSATION SYSTEM OF SPRING OSCILLATION IN TWO–MASS ELECTROMECHANICAL OBJECT (p. 21–26)

Roman Voliansky, Alexander Sadovoy

The paper deals with the synthesis of the precision active compensation system of spring oscillation in the vehicle suspension. The main objective was to develop a method of synthesis of discontinuous control systems of complex dynamic objects, the dynamics of which is generally chaotic.

Using the feedback linearization principle for such systems allows to simplify the control object motion equations by eliminating zero dynamics components, and reduce the motion equations of the simplified object to the Brunovsky form. Unlike the classical feedback linearization, indicated conversions are performed automatically using a specially formed discontinuous control action, the amplitude of which depends on the control object state variables. In the synthesized control system, the controller, forming the control action, along with the considered dynamic object generates an internal motion speed control loop of the sprung mass in the vertical direction and is part of the outer position control loop. To improve the performance of the synthesized system, the position control algorithm has a non-linear switching line, which is determined from the conditions of achieving an aperiodic transient process in the system with variable gain. Using the proposed method is illustrated by the results of the numerical investigation of the synthesized control system. The above material can be useful for experts in the field of electromechanical automation systems and control systems of dynamic objects.

Keywords: relay-operated controller, interval calculations, spring oscillation compensation, variable gain.

References

1. Akimov, L. V., Dolbnia, V. T., Klepikov, V. B., Pirozhok, A. V. (2002). Sintez uproschennyih struktur dvuhmassovyih elektroprivodov s nelineynoy nagruzkoy. Kharkov: NTU "KhPI", 160.
2. Klyuchev, V. I. (2001). Teoriya elektroprivoda. Moscow: Energoatomizdat, 704.
3. Bortsov, Yu. A., Sokolovskiy, G. G. (1992). Avtomatizirovannyiy elektroprivod s uprugimi svyazyami. St– Peterburg: Enegoatomizdat, 288.
4. Burgin, B. Sh. (1992). Analiz i sintez dvuhmassovyih elektromehanicheskih sistem. Novosibirsk: Novosibirskiy ETI im. N. D. Psurtseva, 199.
5. Boyes, W. (1994). Instrumentation Reference Book. Oxford: Butterworth–Heinemann Ltd, 929. doi: 10.1016/B978-0-7506-8308-1.00057-7
6. Sadovoy, A. V., Suhinin, B. V., Sohina, Yu. V. (1998). Sistemy optimalnogo upravleniya pretsizionnymi elektroprivodami. Kyiv: ISIMO, 298.
7. Conde, E. C., Carbajal, F. B., Rodríguez, C. G., Ortega, A. B. (2009). Sliding Mode based Differential Flatness Control and State Estimation of Vehicle Active Suspensions. Politecnología, 1 (1(1)), 49–59.
8. Aldair, A. A., Wang, W. J. (2011). The energy regeneration of Electromagnetic energy saving active Suspension in full vehicle with Neurofuzzy controller. International Journal of Artificial Intelligence & Applications (IJAIA), 2 (2), 32–43. doi: 10.5121/ijaia.2011.2203
9. Gysen, L. J. B., Janssen, J. L. G., Paulides, J. J. H., Lomonova, E. A. (2009). Design Aspects of an Active Electromagnetic Suspension System for Automotive Applications. IEEE Transactions on Industry Applications, 45, (5), 1589–1597. doi:10.1109/08ias.2008.181
10. Emelyanov, S. V., Korovin, S. K. (1997). Novye tipy obratnoy svyazi. Moscow: Nauka, 352.
11. Bartolini, G., Pisano, A., Usai, E. (2009). On the second–order sliding mode control of nonlinear systems with uncertain control direction. Automatica, 45, 2982–2985. doi:10.1016/j.automatica.2009.09.018
12. Dolire, F. O., Salau, T. A. O. (2013). Control of Chaotic Oscillation and Response Charaterisation in Duffing Oscillator Using Vibration Absorber. Journal of Mechanical Engineering and Automation, 3, (1), 1–7. doi:10.5923/j.jmea.20130301.01
13. Sergienko, A. N. (2013). Matematicheskaya model kolebaniy v hodovoy sisteme avtomobilya s elektromagnitnyim dempfirovaniem. Vistnyk KhPI, 31 (1004), 86–93.
14. Kim, D. P. (2004). Teoriya avtomaticheskogo upravleniya. Mnogomernye, nelineynye, optimalnye i adaptivnye sistemy. Moscow: Fizmatlit, 464.
15. Jaulin, L., Kieffer, M., Didrit, O., Walter, E. (2001). Applied interval analysis. London: Springer, 379. doi:10.1007/978-1-4471-0249-6_2
16. Pupkov, K. A., Egupov, N. D. (2004). Metody klassicheskoi i sovremennoi teorii avtomaticheskogo upravleniia. Tom 5. Metody sovremennoi teorii avtomaticheskogo upravleniia. M.: MGTU im. N. E. Baumana, 783.

CONSTRUCTION OF FUNDAMENTAL SOLUTION OF STATIC EQUATIONS OF MEDIUM-THICKNESS ISOTROPIC PLATES (p. 27–34)

Igor Bokov, Elena Strelnikova

A fundamental solution of the elasticity theory equations for isotropic plates was obtained. To construct the two-dimensional elasticity theory equations, the approximation method of displacements, stresses and strains using Fourier series by Legendre polynomials on the transverse coordinate was used. This approach has allowed to take into account the transverse shear and normal stresses. Since the classical Kirchhoff-Love theory does not consider these stresses, the research based on the refined theories of the stress-strain state of isotropic plates under concentrated force actions is an urgent scientific and technical problem. The fundamental solution of these equations was found using the two-dimensional Fourier integral transform and the generalization method, built with a special G-function. The method allows to reduce the system of resolvent differential static equations of flat plates and shells to a system of algebraic equations. Then the inverse Fourier transform restores fundamental solution. Numerical studies that demonstrate behavior patterns of the stress-strain state components depending on the elastic constants of isotropic material were performed. The approach demonstrates the development of the refined theory of plates and shells based on the three-dimensional elasticity theory.

Keywords: refined theory, isotropic plates, static equations, force actions, special G-function.

References

1. Ambartsumyan, S. A. (1974). The general theory of anisotropic shells. Moscow: Science, 446.
2. Goldenveizer, A. L. (1944). Research of the stress condition of the spherical shell. Applied Mathematics and Mechanics, 6, 441–467.
3. Flügge, W. (1966). Concentrated forces on shells. Proceedings of Xlth Internat. Congress of Applied Mechanics. Munich: Springer Verlag, 270–276. doi: 10.1007/978-3-662-29364-5_34
4. Łukasiewicz, S. A. (1976, January). Introduction of concentrated loads in plates and shells. Progress in Aerospace Sciences, Vol. 17, 109–146. doi:10.1016/0376-0421(76)90006-3
5. Darevskii, V. M. (1966). Contact problems of the theory of shells (the action of local loads on the shell). Proceedings of VI All-Union Conference on the theory of shells and plates. Moscow: Nauka, 927–933.
6. Zhigalko, Y. P. (1966). Calculation of thin elastic cylindrical shells at local loads (literature review, methods and results). Investigations in the theory of plates and shells, 4, 3–41.
7. Goldenveizer, A. L. (1954). On the question of the calculation of shells on concentrated forces. Applied Mathematics and Mechanics, 8, (2), 181–186.
8. Vekua, I. N. (1970). Variational principles of the theory of shells. Publisher of Tbilisi, 300.

9. Reissner, E. (1985). Reflections on the theory of elastic plates. Applied Mechanics Reviews, 38, (11), 1453–1464. doi:10.1115/1.3143699
10. Kiel, N. A. (1973). On the action of local loads on the shell. Proceedings of the universities. Construction and architecture, 3, 43–46.
11. Ganowicz, R. (1973). On fundamental singularity in the theory of shallow cylindrical shells. Arch. mech. Stosowanej, 25, (6), 985–992.
12. Jahanshahi, A. (1963). Force Singularities of Shallow Cylindrical Shells. Journal of Applied Mechanics. ASME International, 30, (3), 342–345. doi:10.1115/1.3636559
13. Velichko, P. M., Khizhnyak, V. K., Shevchenko, V. P. (1971). Deformation of shells of positive curvature in the concentrated actions. Stress concentration, 3, (31).
14. Velichko, P. M., Khizhnyak, V. K., Shevchenko, V. P. (1968). Research local stresses in plates and shells under concentrated load. Proceedings of III All-Union Congress on theor. mechanics. M.: Publishing House of the USSR Academy of Sciences, 67.
15. Velichko, P. M., Khizhnyak, V. K., Shevchenko, V. P. (1975). Local stresses in the shells of positive, neutral and negative curvature. Proceedings of X All-Union Conf. on the theory of shells and plates. Vol. 1. Tbilisi: Publishing house Mitsniereba, 31–41.
16. Lukasiewicz, S. (1979). Local loads in plates and shells. Alpen aan den Rijn, Sijthoff and Noordhoff. Warszawa: PWM, 569. doi: 10.1007/978-94-009-9541-3
17. Sanders, J. L. (1970). Singular Solutions to the Shallow Shell Equations. Journal of Applied Mechanics, 37, (2), 361–366. doi: 10.1115/1.3408514
18. Simmonds, J. G., Bradley, M. R. (1976). The Fundamental Solution for a Shallow Shell With an Arbitrary Quadratic Midsurface. Journal of Applied Mechanics, 43, (2), 286–290. doi: 10.1115/1.3423825
19. Vladimirov, V. S. (1976). Generalized functions in mathematical physics. Moscow: Science, 280.
20. Schwartz, L. (1965). Mathematical Methods for the Physical Sciences. Moscow: World, 412.
21. Edwards, R. (1969). Function analysis. Moscow: World, 1071.
22. Vekua, I. N. (1955). A method for calculating prismatic shells. Pr. Tbilis. Mat. Inst., 21, 191–253.
23. Vekua, I. N. (1965). The theory of thin shallow shells of variable thickness. Tbilisi: Metsniereba, 103.
24. Cicala, P. (1959). Sulla teoria elastica della plate sottile. Gorn. Genio civile, 97, (4), 238–256.
25. Poniatowski, V. V. (1962). On the theory of plates of medium thickness. Applied Mathematics and Mechanics, 26, (2), 335–341.
26. Poniatowski, V. V. (1964). On the theory of bending of anisotropic plates. Applied Mathematics and Mechanics, 28, (6), 1033–1039.
27. Poniatowski, V. V. (1967). Refined theory of transversely – isotropic plates. Applied Mathematics and Mechanics, 28, (6), 72–92.
28. Han, H. (1988). Elasticity Theory: Fundamentals of linear theory and its application. Moscow: World, 344.
29. Pelekh, B. L., Lazko, V. A. (1982). Laminated anisotropic plates and shells with stress concentrators. Kiev: Science thought, 296.
30. Sneddon, I. (1955). Fourier transform. Moscow: Foreign literature publishing house, 668.
31. Khizhnyak, V. K., Shevchenko, V. P. (1980). Mixed problem in the theory of plates and shells. DonGU: Donetsk, 128.
32. Dementyev, A. D., Nazarov, L. A., Nazarova, L. A. (2002). Applications of the theory of elasticity. Novosibirsk, 224.

MOTION EQUATIONS OF PLATES OF DIRECT-FLOW VALVES FOR RECIPROCATING COMPRESSORS, WORKING IN THE GAS-LIFT OIL WELL OPERATION SYSTEM (p. 34–38)

Ibrahim Abulfas ogly Gabibov, Natik Sabir ogly Seidahmedov

Despite numerous scientific and practical works on developing and improving self-acting valves, used in reciprocating compressors, the problems associated with ensuring leak-tightness can be considered far from solved. One of the main failure causes of valves is breakage of plates, which leads to leakage of the shut-off assembly. Frequent changes of process parameters, especially gas pressure, caused by the mechanical vibrations of the plate during closure leads to breakage. The correct definition of the parameters of valve plates is important. Existing motion equations of the plate of direct-flow valves do not allow to fully assess their performance in the gas-lift operation system. In the paper, an attempt to derive the motion equation of the plates of direct-flow valves, which are operated in these conditions was made.

Keywords: reciprocating compressors, direct-flow valves, vibration of plate, leak-tightness, elasticity; rigidity, associated petroleum gas, gas-lift operation.

References

1. Asadov, O. S., Aliev, V. I., Makarov, V. V. (2011). Novyj nauchnyj podhod k opredeleniju real'noj proizvoditel'nosti porshnevyh kompressorov v sistemah gazlifta i transporta gaza. Moscow: Izd-stvo «Sputnik+», 243.
2. Aliev, V. I. (2007). Nauchnye osnovy povyshenija jeffektivnosti raboty gazomotokompressorov v sistemah gazlifta i transporta gaza morskih mestorozhdenij Azerbajdzhana. Baku, 317.
3. Dollezhal', N. A. (1962). Raschet osnovnyh parametrov samodejstvujushhego klapana porshnevogo kompressora. Moscow, 242.
4. Frenkel', M. I. (1969). Porshnevye kompressory. M.-L. Mashgiz, 743.
5. Borohovich, A. I., Kolbasov, M. G. (1967). Uravnenie dvizhenija plastiny prjamotochnogo klapana porshnevogo kompressora. Izvestija VUZov serija «Gornyj zhurnal», 7, 130–134.
6. Dodin, Ju. S., Klochkov, V. I., Luk'janica, A. I. (2009). Klapany porshnevyh kompressorov. Novomoskovsk, 140.
7. Priluckij, A. I. (2006). Vpusknye klapany porshnevyh detanderov s diskovymi nemetallicheskimi plastinami. Himicheskoe i neftegazovoe mashinostroenie, 4, 36–39.
8. Zagorodnikov, A. P. (2011). Razrabotka i sovershenstvovanie metodov raschèta rabochih processov porshnevyh rasshiritel'nyh mashin i agregatov s samodejstvujushhimi klapanami. Omsk, 18.
9. Shkurkov, A. Ju. (2006). Issledovanie ustalostnyh svojstv stalej dlja prjamotochnyh klapanov porshnevyh kompressorov. Kursk.
10. Glinnikova, T. P. (2013). Obosnovanie i vybor parametrov prjamotochnyh klapanov rudnichnyh porshnevyh kompressorov. Ekaterinburg, .
11. Volegov, S. A. (2008). Obosnovanie konstruktivno-tehnologicheskih parametrov zapornyh organov porshnevyh kompressorov. Ekaterinburg.
12. Timoshenko, S. P. (1965). Soprotivlenie materialov. Vol. 1. Moscow: Nauka, 365.
13. Filonenko-Borodich, M. F. (2012). Teorija uprugosti. Moscow, 365.

ANALYSIS OF PROPAGATION OF WEAKLY NONLINEAR WAVES IN A TWO-LAYER FLUID WITH FREE SURFACE (p. 39–44)

Olga Avramenko, Volodymyr Naradovy

The study of wave motions in stratified fluids is one of the main tasks of hydrodynamics, which is caused by both theoretical and practical needs.

Analytical analysis of propagation of weakly nonlinear wave packets in a two-layer fluid of finite depth in the presence of a free surface is performed. As a result, evolution equations of wave packets on the interface and the free surface in the form of the second-order nonlinear differential Schrödinger-type equations were derived. The form of internal and surface waves depending on the ratio of layer densities and the wave number considering the surface tension was analyzed. As a result, the effects of taking into account the second approximation in modeling wave motions in the two-layer system, which leads to blunting or sharpening of the wave crests and troughs were revealed. The analytical results are confirmed by field observations.

Keywords: nonlinear waves, two-layer fluid, wave packet form, free surface.

References

1. Docenko, S. F., Ivanov, V. A., Poberegnuy, Y. A. (2010). Svyaz obrazovaniya voln-ybiyc I meterologicheskih ysloviy v severo-zapadnoy chasti Chernogo moray. Dopovidi NAN Ykrainu, 12, 105–109.
2. Docenko, S. F., Sannikova, N. K. V. (2011). Analiz dvymernogo rasprostraneniya voln cynami iz elipticheskogo ochaga v pryamolineynuy kanal. MGI NAN Ykrainu, 419–428.
3. Kilinichenko, V. A., Sekerg-Zenkovich, S. Ya. (2007). Eksperimentalnoe issledovanie voln Faradeya maksimalnoy vusotu Izv. RAN MGG, 6, 103–110.
4. Kilinichenko, V. A., Sekerg-Zenkovich, S. Ya. (2008). Eksperimentalnoe issledovanie vtorichnuh stacionarnuh techeniy v poverhnostnuh volnah Faradeya. Izv. RAN MGG, 1, 141–148.

5. Nayfeh, A. H. (1976). Nonlinear Propagation of Wave-Packets on Fluid Interfaces. Journal of Applied Mechanics, 43 (4), 584–588. doi: 10.1115/1.3423936
6. Selezov, I. T., Avramenko, O. V. (2002). Stryktyra nelineynuh volnovuh paketov na poverhnosti kontakta gidkih sred. Prukladna gidromehanika, 4 (76), 3–13.
7. Selezov, I. T., Avramenko, O. V. (2001). Ystoychivost volnovuh paketov v sloistuh gidrodinamicheskih sistemah s ychetom poverhnostnogo natyageniya. Prukladna gidromehanika, 3 (75), 38–46.
8. Selezov, I. T., , O. V. (2001). Evolycionnoe yravnenie tretego poryadka dlya nelineynuh volnovuh paketov pri okolokriticheskih volnovuh chislah. Dinamicheskie sistemu, 19, 58–67.
9. Selezov, I. T., Avramenko, O. V. (2001). Evolyciya nelineynuh volnovuh paketov v gidrodinamicheskoy sisteme "sloy – polyprostranstvo" s ychetom poverhnostnogo natyageniya. Mat. metodu i fizuko-mehanichni polya, 44, 113–122.
10. Vincze, M., Kozma, P., Gyüre, B., Jánosi, I. M., Gábor Szabó, K., Tél, T. (2007). Amplified internal pulsations on a stratified exchange flow excited by interaction between a thin sill and external seiche. Journal of Applied Mechanics, 19 (10), 108108-1–108108-4. doi: 10.1063/1.2796182
11. Makarenko, N. N., Malceva, J. L. (2008). Asimptoticheskie modeli vnytrennih stacionarnuh voln. Prikl. mehanika i teh. fizika, 49 (4), 151–161.
12. Debsarma, S., Das, K. P. (2007). Fourth-order nonlinear evolution equations for a capillary-gravity wave packet in the presence of another wave packet in deep water. Physics of Fluids, 19 (9), 097101–097101. doi: 10.1063/1.2772252
13. Carr, M., Davies, P. A. (2006). The motion of an internal solitary wave of depression over a fixed bottom boundary in a shallow, two-layer fluid. Phys. Fluids, 18 (1), 016601–016601. doi: 10.1063/1.2162033
14. Sutherland, B. R., Nault, J. T. (2007). Intrusive gravity currents propagating along thin and thick interfaces. Journal of Fluid Mechanics, 586, 109–118. doi: 10.1017/s0022112007007288
15. Haciyev, B. I. (2006). Unstationary waves in two-layered fluid caused by normal loading at the interface. Proc. IMM (Inst. Mathematics and Mechanics) NAS of Azerbaijan, 119–126.
16. Selezov, I. T., Avramenko, O. V.,Gyrtovyy, Y. V., Naradovyy, V. V. (2009). Nelineynoe vzaimodeystvie vnytrennih i poverhnostnuh gravitacionnuh voln v dvyhsloynoy gidkosti so svobodnoy poverhnosty. Mat. metodu i fizuko-mehanichni polya, 52, 72–83.
17. Selezov, I. T., Krivonos, Y. G. (2012). Matimaticheskie metodu v zadachah rasprostraneniya I difrakcii voln. Kiev: Naykova dymka, 232.
18. Naradovyy, V. (2013) Interaction of internal and surface waves in two-layer fluid with free surface/Challenges of Modern Tehnology, 3 (4), 103–106.

THEORETICAL AND EXPERIMENTAL INVESTIGATIONS OF FACE BUFFER IMPULSE SEALS WITH DISCRETE SUPPLYING (p. 45–52)

Andriy Zahorulko

Analytical calculation technique and results of numerical and experimental investigations of two-stage face impulse seals with discrete supplying and with coaxial arrangement of stages are presented. As the common friction pair is divided in radial direction by discharge chambers into two sealing stages, the design of assembly is essentially simplified and its dimensions are decreased, keeping increased reliability and hermetic sealing. Mechanism of operation of such a seal is based upon impulse balancing of friction pair and creating of a guaranteed self-regulated gap. This simple, robust and compact design provides greater intrinsic reliability than traditional gas seal designs. The theoretical static and flow characteristics are compared with experimental results and coincidence within 5 % are obtained.

Keywords: buffer impulse seal, experimental investigations, static and flow characteristics, simulation, pump.

References

1. Sattler, M. (2009). A new oil barrier seal for dry gas seals. Sealing Technology, 2009 (9), 8–11. doi: 10.1016/s1350-4789(09)70495-7
2. Pat. 6076830 USA, F 16 J 15/34. Dual Non-Contacting Mechanical Face Seal Having Concentric Seal Faces.
3. Lebeck, A. O. (1991). Principle and design of mechanical face seals, John Wiley & Sons Inc. New York, Chichister, Brisbane, Toronto and Singapore, 553.
4. Tran, H., Haselbacher, P. (2004). High-performance lift augmentation dynamic seals for turbine bearing compartments. Sealing Technology, 2004 (1), 5–10. doi: 10.1016/s1350-4789(04)00187-4
5. Neuberger, S., Bock, E., Haas, W., Lang, K. (2014). Gas-lubricated mechanical face seals reduce CO_2 emissions. Sealing Technology, 2014 (9), 8–12. doi: 10.1016/s1350-4789(14)70343-5
6. Wang, Y., Yang, H., Wang, J., Liu, Y., Wang, H., Feng, X. (2009). Theoretical Analyses and Field Applications of Gas-Film Lubricated Mechanical Face Seals with Herringbone Spiral Grooves. Tribology Transactions, 52 (6), 800–806. doi: 10.1080/10402000903115445
7. Meck, K.-D., Zhu, G. (2008). Improving mechanical seal reliability with advanced computational engineering tools, part 1: FEA. Sealing Technology, 2008 (1), 8–11. doi: 10.1016/s1350-4789(08)70023-0
8. Meck, K.-D., Zhu, G. (2008). Improving mechanical seal reliability with advanced computational engineering tools, part 2: CFD and application examples. Sealing Technology, 2008 (2), 7–10. doi: 10.1016/s1350-4789(08)70120-x
9. Martsynkovsky, V. A. (1980). Non-Contact Seals of Rotor Machines. Moscow: Mashinostroenie, 200.
10. Martsynkovskyy, V. A., Vorona, P. N. (1987). Pumps for Nuclear Power Plants. Moscow: Enegroatomizdat, 256.
11. Gaft, J., Martsinkovskyy, V., Gromyko, B., Zahorulko, A. (2003). Design and calculation of mechanical seals with self-adjusting clearance. Proc. XVII Int. Conf. on Fluid sealing, BHR Group, York, England, 505–520.

THE EFFECT OF FRICTION ON THE STAMP'S FLAT SOLE COMING OFF THE SOLE BASE (p. 53–56)

Ivan Aleksandrov, Arkady Pvivarnikov

The study provides an algorithm for precise determining of the contact pressure under a flat-solestamp that is pressed into an elastic laminated multilayer base with any finite number of layers. We have taken into account the friction between the stamp and the base whose contact was one-sided. The algorithm can solve fundamentally new contact problems of elastic multilayer media. As an example, we have solved the problem of a cylindrical flat-sole stampindented in a two-layer base for two cases. In the first case, in contrast to the second, friction was not taken into account. A distinctive feature of the two-layer base is its top layer that is much stiffer than the lower one. We have found that in the first case the two-layer base partially comes off the stamp, while in the second caseit does not. Ultimately, the suggested algorithm can reduce the safety factors for strength and rigidity in calculations of real multilayer structures.Consequently, it can reduce consumption of materials and cost of the structures.

Keywords: elastic two-layer base, flat-solestamp, the Coulomb friction,coming off.

References

1. Kravchuk, A. S. (2009). Variacionnyj metod v kontaktnyh zadachah. Sostojanie problemy, napravlenija razvitija. Prikl. matemat. i mehanika, 73 (3), 492–502.
2. Reina, S., Dini, D., Hills, D. A., Iida, Y. (2011). A quadratic programming formulation for the solution of layered elastic contact problems: Example applications and experimental validation. European Journal of Mechanics – A/Solids, 30 (3), 236–247. doi: 10.1016/j.euromechsol.2010.12.003
3. Aleksandrov, A. I. (2012). Reshenie zadach o kontakte uprugih tel s ispol'zovaniem nelinejnyh integral'nyh uravnenij. Dop. Nacional'noi akademii nauk Ukraini, 11, 47–52.
4. Aleksandrov, V. M., Kalker, J. J., Pozharskij, D. A. (1999). Prostranstvennaja kontaktnaja zadacha dlja dvuhslojnogo uprugogo osnovanija s zaranee neizvestnoj oblast'ju kontakta. Izv. RAN. MTT, 4, 51–55.
5. Chebakov, M. I. (2002). Trjohmernaja kontaktnaja zadacha dlja sloja s uchjotom sil trenija v oblasti kontakta. Izv. RAN. Mehanika tvjordogo tela, 6, 29–42.
6. Sundaram, N., Farris, T. N. (2010). Mechanics of advancing pin-loaded contacts with friction. Journal of the Mechanics and Physics of Solids, 58 (11), 1819–1833. doi: 10.1016/j.jmps.2010.08.004

7. Ostrik, V. I. (2004). Kontaktnoe vzaimodejstvie shtampa s uprugoj poluploskost'ju pri nalichii trenija i sceplenija. Teor. i prikl. mehanika, 39, 94–101.
8. Ostrik, V. I. (2011). Vdavlivanie shtampa v upruguju polosu pri nalichii trenija i sceplenija. Izv. RAN. Mehanika tvjordogo tela, 5, 119–129.
9. Kolosova, E. M., Chebakov, M. I. (2012). Kontaktnye zadachi dlja trjohslojnoj polosy pri nalichki sil trenija. Prikl. matemat. i mehanika, 76 (5), 795–802.
10. Stoljarchuk, I. A. (2006). Periodychna kontaktna zadacha ploskoi' teorii' pruzhnosti dlja bagatosharovyh osnov. Dynamika naukovyh doslidzhen' – 2006. Dnipropetrovs'k, 7, 11–15.
11. Matuzko, Ju. O. (2004). Prostorovi kontaktni zadachi dlja pruzhnoi' bagatosharovoi' osnovy z gladkoju mezheju. Donec'k, 22.
12. Privarnikov, A. K., Lamzjuk, V. D. (1985). Uprugie mnogoslojnye osnovanija. Dep. v VINITI 23.12.8, 8789 –V, 162.
13. Aleksandrov I. O. (2015). Prostorova kontaktna zadacha pro diju shtampa z ploskoju pidoshvoju na pruzhnu bagatosharovu osnovu z urahuvannjam tertja mizh shtampom i osnovoju. Visnyk ZNU. Fizyko-matematychni nauky, 3, 54–64.

LOWERING OF TECHNOLOGICAL RISKS OF HYPERSOUND AERONAVIGATION (p. 57–61)

Volodimir Karachun, Viktorij Mel'nick

The study reveals the mechanism of an acoustic error of an inertial sensor with a float static liquid suspension. The paper presents a numerical analysis of the autonomous positioning error that used to pose a technological risk. We have disclosed the characteristics of the device dynamics in a non-inertial frame of reference and revealed the dependence of kinematic parameters in the base and the mobile systems.

The paper describes the nature of additional precession in the inertial sensor in the operating conditions of a hypersonic flight caused bythe Euler force and analyses the device's gyroscopic response to the moments of the Coriolis effect on the precession axis in the impedance float surface.

The findings can be used in hypersonic aircraft for assault and foreign intelligence. They can improveserial production of hypersonic technologies to the desired level, reducing technological risks of the vehicles'operational use.

Keywords: hypersonic technology, inertial sensors, penetrating acoustic radiation, impedance phase, error.

References

1. Kulyk, M. S., Mel'nyck, V. M., Karachun, V. V., Ladogubets, N. V. (2015). Suborbital and Atmospheric Hypersound Technologies. Kiev, Ukraine: NAU, 328.
2. Karachun, V. V., Ladogubets, N. V., Mel'nyck, V. M. (2014). Supersonic aircraft. Kiev, Ukraine: NAU, 240.
3. Mel'nyck, V. M. Float gyroscope. Ukrainian Patent No. 85150. 11 Nov. 20013, 1.
4. Winter, F. H., Van der Binder, F.R. (2003). 100 years of flight: a chronicle of aerospace history, 1903–2003. Reston, Virginia: American Institute of Aeronautics and Astronautics, 524.
5. Barbour, N. M. (2010). Inertial Navigation Sensors. Cambridge, 10.
6. Nwe, T. T. (2008). Application of an Inertial Navigation System to the Quad-rotor UAV using MEMS Sensors. Engineering and Technology, 42, 578–582.
7. Woodman, O. J. (2007). An introduction to inertial navigation. Cambridge, 37.
8. Le Manh Hung, V. (2009). Indoor Navigation System for Handheld Devices. Worcester, 198.
9. Nasiri, S. A. (2004). Critical Review of MEMS Gyroscopes Technology and Commercialization Status. California, 8.
10. Karachun, V. V, Shibetskij V. Y. (2012). Passive methods of error reduction of floating gyroscope under the N-wave. Eastern-European Journal of Enterprise Technologies, 5/7 (59), 8–10. Available at: http://journals.uran.ua/eejet/article/view/4149/3912
11. Zaborov, V. I. (1962). The theory of insulation walling. Moscow, USSR: Stroyizdat, 116.
12. Heng, M., Erkorkmaz, K. (2010). Design of a NURBS interpolator with minimal feed fluctuation and continuous feed modulation capability. International Journal of Machine Tools and Manufacture, 50 (3), 281–293. doi: 10.1016/j.ijmachtools.2009.11.005

A STUDY OFPOLYGRADIENT MEDIA STRUCTURE REGULARITIES (p. 62–67)

Iryna Shvedchykova, Igor Lutsenko, Julia Romanchenko

We have proved that the choice of the structure of poligradient media is one of the most important stages in new designs of magnetic separators. Ferromagnetic solids are considered as generating elements of the internal structure of poligradient media, which are elementary monostructuresof various geometric forms that, in terms of genetic concepts, are the parental chromosomes. We have specified that the genetic synthesis algorithms are based on genetic synthesis operators—in particular, on the genetic operators of crossover, replication, mutation,and spatial inversion. We have proved that the problem of selecting a poligradient medium in the working bodies of the separator must be solved through structural synthesis and, in the future, taking into account the properties of the medium, also parametric synthesis. Using genetic operators, we have synthesized an inner structure of a poligradient medium, in which an elementary monostructure generating unit is an isosceles triangle-shaped plate. The reliability of the research findings has been confirmed.

Keywords: magnetic separator, poligradient medium, synthesis, genetic operator, generating structure.

References

1. Zagirnyak, M. V., Branspiz, Yu. A., Shvedchikova, I. A. (2011). Magnitnye separatory. Problemy proektirovanija. Kiev: Tehnika, 224.
2. Oberteuffer, J. (1974). Magnetic separation: A review of principles, devices, and applications. IEEE Transactions on Magnetics, 10 (2), 223–238. doi: 10.1109/tmag.1974.1058315
3. Svoboda, J. (1987). Magnetic Methods for the Treatment of minerals. Elsevier, 692.
4. Unkelbach, K. H. (1990). Magnetic separators mode of operation and applicability for the separation of materials. KHD Humboldt Wedag AG, 87.
5. Zagirnyak, M. (2008). Magnetic Separators. Proceedings of the seventeenth International Electrotechnical and Computer science Conference ERK, Portorož, 7–8.
6. Zagirnyak, M. V., Volkonanin, E. E. (2014). Separacija nanochastic po frakcijam s ispol'zovaniem magnitnoj sistemy Faradeja. Izvestija vuzov. Jelektromehanika, 4, 30–34.
7. Moeser, G. D., Roach, A. R., Green, W. H., Alan, T. (2004). Hatton High-Gradient Magnetic Separation of Coated Magnetic Nanoparticles. American Institute of Chemical Engineers, 50, 2835–2848.
8. Tagunov, P. E., Tagunov, E. Y. (2012). Opredelenie silovyh harakteristik poligradientnoj sharikovoj sredy v magnitnom pole. Gornyj informacionno-analiticheskij bjulleten' MGGU, 2, 117–121.
9. Kondratenko, I. P., Nekrasov, A. V., Volkanyn, E. E. (2012). Jelektrotehnicheskaja sistema s sostavnymi sterzhnjami dlja vysokogradientnoj magnitnoj separacii. Elektrotehnika i elektromehanika, 2, 38–41.
10. Volkanyn, E. E., Nekrasov, A. V., Oksanych, A. P. (2012). Opredelenie balansa sil, dejstvujushhih na nanochasticu v jelektrotehnicheskoj sisteme magnitnoj separacii. Elektrotehnika i elektromehanika, 2, 28–31.
11. Tolmachev, S. T., Bondarevskiy, S. L. (2012). Nekotorye voprosy poligradientnoj magnitnoj separacii. Elektromehanichni i energozberigajuchi sistemi, 17, 31–36.
12. Tolmachev, S. T., Bondarevskiy, S. L. (2013). Classification of heterogeneous structures and conditions of their doubly periodicity. Eastern-European Journal of Enterprise Technologies, 5/5 (65), 24–28. Available at: http://journals.uran.ua/eejet/article/view/18108/15853
13. Shinkarenko, V. F. (2002). Osnovy teorii' evoljucii' elektromehanichnyh system. Kiev: Naukova dumka, 288.
14. Kuznetsov, J. N., Shinkarenko, V. F. (2012). Geneticheskij podhod k sozdaniju slozhnyh tehnicheskih sistem. Tehnologichni kompleksi, 1 (2), 21–29.
15. Shvedchikova, I. A., Romanchenko, Y. A. (2014). Klassifikacija poligradientnyh magnitnyh separatorov. Vestnik NTU «HPI», 19, 64–76.
16. Shvedchikova, I. A., Romanchenko, Y. A. (2015). Strukturno-sistemnyj analiz poligradientnyh magnitnyh separatorov. Praci Tavrijs'kogo derzhavnogo agrotehnichnogo universytetu, 2, 117–125.
17. Shinkarenko, V. F., Zagirnyak, M. V., Shvedchikova, I. A. (2010). Structural-Systematic Approach in Magnetic Separators De-

sign. Studies in Computational Intelligence, 327, 201–217. doi: 10.1007/978-3-642-16225-1_11

18. Shinkarenko, V. F., Zagirnyak, M. V., Shvedchikova, I. A. (2010). Methods for using intertype homology for synthesizing new structural versions of magnetic separators. Russian Electrical Engineering, 81 (9), 504–508. doi: 10.3103/s1068371210090105
19. Zagirnyak, M. V., Shvedchikova, I. A. (2010). Geneticheskij sintez struktur magnitnyh separatorov: Tehnicheskaja jelektrodinamika, 4, 43–47.
20. Zagirnyak, M., Shvedchikova, I., Miljavec, D. (2011). Forming a genetic record of cylindrical magnetic separator structures. Przeglad elektrotechniczny (Electrical Review), 3, 220–223.
21. Zagirnyak, M., Shvedchikova, I., Tkach, S. (2014). Automation design of multi-unit electromechanical structures of magnetic separators. Przegląd elektrotechniczny (Electrical Review), 12, 292–295.
22. Shvedchikova, I. A., Romanchenko, Y. A. (2015). Elektromagnitnyj separator. Zajavka na Patent Ukrai'ny na korysnu model' u201504324 MKY3 V 03 S 1/00.